RECENT EXPERIENCE IN USING FINITE ELEMENT METHODS FOR THE SOLUTION OF PROBLEMS IN AERODYNAMIC INTERFERENCE

by

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SUMMARY

Because of the mathematical complexities involved, there have been few closed-form analytic solutions to problems in aerodynamic interference. Among the numerical techniques available, the method of finite elements shows considerable promise because of its ability to handle configurations of arbitrary geometry.

For solving problems of flow about airplane configurations by the method of finite elements, one combines a discrete set of elementary solutions of the linearized equations of gasdynamics in such a way that the boundary condition of zero flow through the physical surface is satisfied at a large number of control points on the surface. Experience has shown that calculations using discrete elements and discrete control points produce solutions consistent with closed-form solutions that satisfy the boundary conditions everywhere.

In view of the success of the method in predicting the flow about simple wing-body combinations, an existing computer program is being expanded to include bodies other than the main fuselage. This paper contains a brief review of the current NASA Ames program and the expanded version as well as some recommendations for future research.

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1. Introduction

In October 1969, a symposium was held at the NASA Ames Research Center on the subject of "Analytic Methods in Aircraft Aerodynamics" (1). A brief survey of the papers given at this conference will demonstrate that we have reached a new stage in theoretical aerodynamics. No longer are we using computers to automate procedures that were conceived and developed with the intent of making numerical calculations by desk calculators. New developments in theoretical aerodynamics are largely based on numerical procedures to be implemented on high-speed computing machines. It was especially interesting to note the widespread interest in attempting solutions of "exact" equations of gasdynamics by numerical methods. In view of this work, it is no longer necessary to introduce a paper on finite element methods by showing their superiority to closed-form solutions. Instead, we must explain why these methods (that represent a curious mixture of analytic and numerical theory) are worthy of further development in view of the successful introduction of methods that are purely numerical. The answer lies in the ease with which solutions can be generated by finite elements for problems with very complex boundary conditions. The purely numerical methods require calculations throughout a three-dimensional grid or lattice. For a highly complex airplane configuration, the organization and orderly use of such data present very difficult problems. For this reason, we have continued to develop our computing procedures based on finite elements and in this paper some of the features of the most recent versions of our programs for estimating airplane aerodynamics are discussed.

2. Representative Finite Element Approaches

Many investigators have developed computer programs based on superposition of finite elements. For example, there is the incompressible potential flow program developed by Hess and Smith at Douglas (2) and the "fan-in-wing" program developed by Rubbert and others at Boeing (3). There are also numerous planar and nonplanar lifting surface programs, a summary of which can be found in (4). Wing-pylon-nacelle interference at subsonic speeds is treated in (5) while supersonic nacelle-on-wing interference is described in (6). For wing-body interference, there is the procedure based on the subsonic-supersonic lifting surface elements described by Woodward (7) and the subsonic vortex lattice procedures developed by Kalman, Rodden, and Giesing (8). This wealth of procedures indicates the essential soundness of the finite element approach and also illustrates the fact that special programs can be developed for special problems with reasonable effort.

3. The Ames Wing-Body Computer Program

Since 1964 Ames Research Center has supported the development and distribution of computer programs for predicting the aerodynamic characteristics of wing-body combinations, and in January 1970, copies of the latest version of this program were made available. In this procedure, a wing-body combination is represented by a collection of line sources and doublets and surface panels representing thickness and lift. Fig. 1 (taken from (9)) summarizes the elements used for the simulation. The panels used are those described by Woodward (7). The use of several different types of elements distinguishes this procedure from most other finite element procedures. The variety of elements places a greater burden on the logic of the program but enables one to obtain good solutions with a small number of panels. The present version of the program will accept a wing-body combination consisting of one body of revolution in combination with wings of arbitrary planform, camber, twist, and dihedral. In principle, any number of wings and tail planes can be represented; however, there is a limit of 100 surface panels available for representing the wings. Similarly, the number of body surface panels cannot exceed 100. (Note: these figures apply to the right half of the configuration; the panels on the left half are included implicitly and do not figure in the count.)

A new program that will treat a configuration with as many as 10 bodies and 20 wing segments is being developed. (Wings are made up of trapezoidal segments, *e.g.,* the configuration in Fig. 2 has five wing segments.) As many as 256 panels are allowed on the wing surfaces and 256 on the body surfaces. With this capability, it will now be possible to simulate the geometry of an actual airplane rather than just a wing and body (Fig. 3). Bradley and Miller (10) used a modified version of this program to describe some results for the B-58 and F-111 airplanes.

4. Future Research and Development in Finite Element Methods

The developments reported here and elsewhere indicate that finite element procedures can generate accurate solutions to linear equations of flow about arbitrary airplane configurations. It seems appropriate at this point to indicate some areas for which deficiencies remain in the existing procedures in order to stimulate further research toward improving them.

a. *Trailing singularities* – Discrete lifting elements have a pair of trailing vortices. This is a correct physical representation, but in real flow these vortices do not simply follow the free-stream direction from the trailing edge of the panel. An accurate physical description of the flow requires that these trailing vortices be properly located, especially for wing-tail configurations.

b. *Bodies with variable diameter in the region of wing-body interference* – A problem arises here, which is related to the trailing vortex problem mentioned above, when lifting surface elements are used to account for interference. If panels are placed on the physical surface of the body, the wake of the body will consist of concentric circles of shed vorticity. This is clearly not a correct physical representation, but neither is the common approach of using a mean cylinder (*e.g.,* Fig. 16 of (10)) because the boundary conditions are not satisfied at the proper position.

c. *Bodies with noncircular cross section* – It has been demonstrated (*e.g.,* by the Hess-Smith program (2)) that bodies of noncircular cross section can be accommodated, but a great number of panels is required. One of the most desirable features of the

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mixed-singularity (Woodward) approach is the small number of panels required on the body surface because the line singularities give the proper flow field about the isolated body. Higher order line multipoles could be used in conjunction with lift panels located on the true surface.

d. *Sideslip* – The work to date has concentrated on predicting longitudinal effects, but sideslip characteristics are equally important and it should be possible to develop computing procedures for these values. Rubbert (11) has concluded that procedures in which the span loading has finite steps (this includes all existing procedures) cannot predict the effects of sideslip accurately. Such calculations need new elements that generate a continuous span load distribution.

e. *Induced drag* – The infinite pressure differential predicted by first-order theory at the subsonic leading edges of wings gives rise to erroneous induced drag estimates for wings with rounded leading edges. This failure to predict the so-called "leading-edge thrust" could be resolved by proper application of exact boundary conditions. Experimentally measured drag frequently does not agree with either the zero suction or full suction drag predictions. This subject requires further enlightment.

5. Conclusions

The development of finite element methods has matured to the point that it is feasible to obtain solutions for configurations that closely resemble the geometry of actual airplanes. Future refinements should extend this capability still further. Because of the versatility and ease with which complicated boundary conditions may be simulated, the generation of solutions by superposition of finite elements appears to be the most promising approach to the theoretical prediction of aerodynamic interference.

6. References

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- BODY THICKNESS BY LINE SOURCES
- BODY LIFT BY LINE DOUBLETS
- WING THICKNESS BY CONSTANT SOURCE PANELS
- WING LIFT BY CONSTANT PRESSURE PANELS
- WING-BODY INTERFERENCE BY CONSTANT PRESSURE PANELS

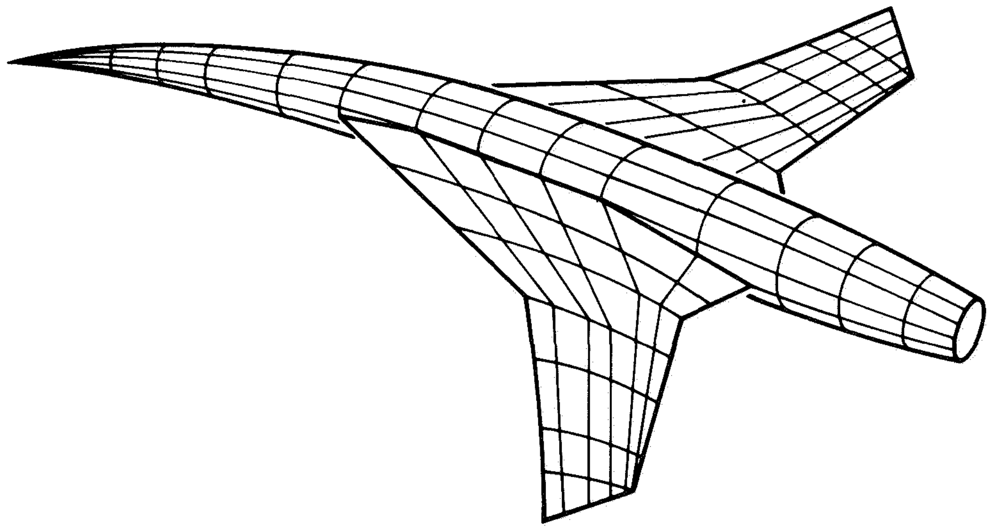

Fig. 1 – Combination of Finite Elements to Represent Wing-Body Combination.

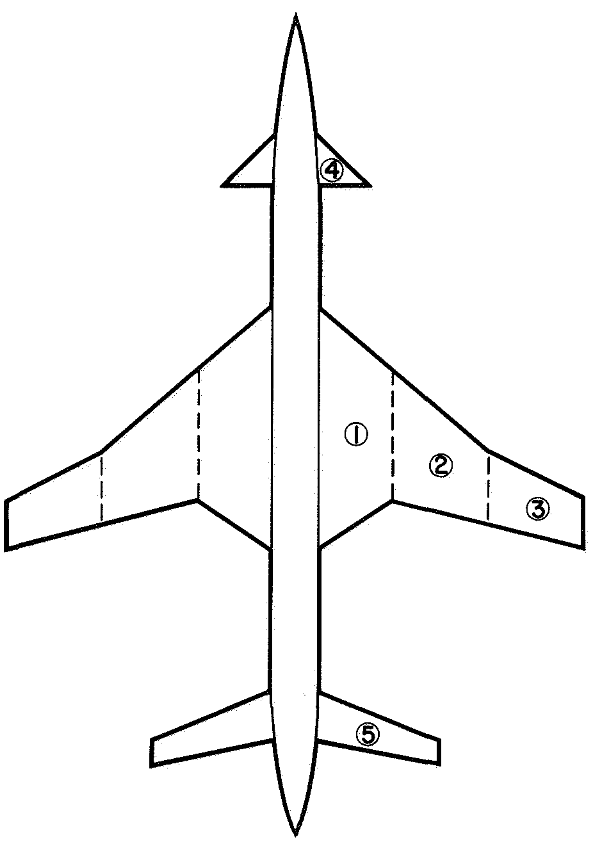

Fig. 2 – Wing Segments of an Airplane Configuration.

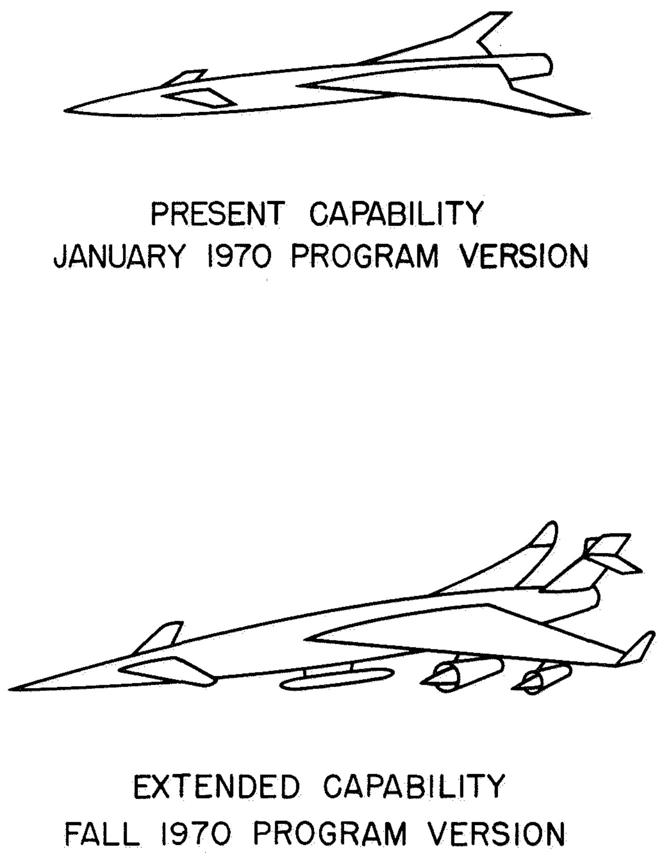

Fig. 3 – Present and Extended Capability of Computer Programs.